Making of the Atomic Bomb Notes

This presentation addresses what led the U.S. to make atomic bombs, the establishment of the World War II Manhattan Project, what it takes to weaponize uranium, how plutonium is produced and weaponized, why the plutonium bomb had to be tested, and the opposition of some Manhattan Project scientists to using the bombs against Japan.

Slide 5 – location of major Manhattan Project sites graphic

- map shows locations of primary laboratories and facilities involved in development of American atomic bomb – Oak Ridge, TN; Metallurgical Laboratory (Chicago); Los Alamos, NM; and Hanford, WA
- Manhattan, NY was headquarters of Manhattan Engineer District
- Wendover Army Airfield in Utah was training base for bomber pilots, including crew of Enola Gay, in WW II

Slide 6 – Manhattan Project programs graphic

- graphic identifies major Manhattan Project programs and locations
- uranium enrichment facilities located at Oak Ridge, TN
- atomic bomb design and production activities took place at Los Alamos, NM
- plutonium production and processing facilities located at Hanford, WA

Slide 8 – establishing Los Alamos

- only people who worked there and handful of people in Washington knew of laboratory's existence – existed only as post office box in Santa Fe from 1942 to late 1945

Slide 9 – natural uranium composition graphic

- graphic shows isotopic composition of natural uranium
  - about 99% U-238
  - less than 1% U-235
- two isotopes of natural uranium differ by three neutrons in atomic nucleus
- Niels Bohr identified U-235 as isotope of uranium that fissions under low energy neutron bombardment in 1939

Slide 10 – U-235 and U-238 fission cross-sections graphic

- fission cross-section is measure of probability that uranium atom will capture a neutron that produces fission
  - cross-section given in unit called barn, which is 1×10^{-24} square centimeter

- graphic shows how U-235 and U-238 fission cross-sections vary with neutron energy (note log scales for both neutron energy and fission cross-section)
- since fission neutrons born with average energy of 1 million electron volts (MeV), probability that U-238 atom will fission even with 1 MeV neutrons is negligible compared to U-235 fission, as shown in graphic

Slide 11 – U-235 fission graphic

- slide shows what happens when U-235 fissions
- key to nuclear fission is that fission reaction produces extra neutrons (usually 2 or 3) that can sustain chain reaction
- end products of U-235 fission event are lighter isotopes called fission fragments that are radioactive
- in addition, prompt and delayed gamma-rays emitted

Slide 12 – weaponizing uranium graphic

- about 90% U-235 required for atomic bomb, so weaponizing uranium anything but straightforward
- since U-235 and U-238 chemically identical, only way to separate two isotopes is by difference in mass of three neutrons in atomic nucleus

Slide 13 – uranium project

- Arthur Compton worked with Enrico Fermi in calculating critical mass of uranium-235 for test reactor, discussed prospects for uranium enrichment with Harold Urey, and prospect of using nuclear reactor to produce plutonium with Eugene Wigner
- achievement of self-sustaining fission chain reaction necessary to determine feasibility of military use of nuclear energy and whether Nazi Germany could succeed in producing nuclear weapons
- uranium separation process was going to require lots of electricity; eastern Tennessee had abundant electricity from TVA hydroelectric facilities

Slide 15 – Chicago Pile 1 graphic

- developed by Metallurgical Laboratory at University of Chicago, CP-1 built under west viewing stands of Stagg Field
- on December 2, 1942, Enrico Fermi and associates demonstrated to world that achieving self-sustaining fission chain reaction possible using natural uranium and very pure graphite to moderate (slow down) fission neutrons
- prior to CP-1, estimates of critical masses of uranium had been crude calculations, leading to order-of-magnitude uncertainties about size of hypothetical atomic bomb
- success of CP-1 demonstrated

- feasibility of nuclear reactor with self-sustaining fission chain reaction
- average number of secondary neutrons from U-235 fission (2.4) larger than originally thought (1.73)
- feasibility of military use of nuclear energy (i.e., an atomic bomb)

Slide 17 – Y-12 electromagnetic separation plant

- for uranium isotope separation process, natural uranium first converted to gas – uranium tetrachloride
- gas then ionized and passed over very strong electromagnets (calutrons)
  - electromagnetic field diverted trajectory of ionized gas stream to make arc
  - very small amount of heavier molecule, making slightly larger arc, removed from main gas stream
- after passing through 1150 calutrons, enough of heavier molecule removed such that main stream was 90% U-235 tetrachloride
- gas then converted back to solid uranium
- photo on right of slide shows Alpha stage of Y-12 facility containing 96 calutrons arranged in oval racetrack
- by August 1945, enough highly-enriched uranium created for one and one-half uranium atomic bombs

Slide 18 – calutron graphic

- graphic shows how calutron worked
- very strong magnetic field, perpendicular to calutron chamber, pulled ions into an arc, with heavier U-238 tetrachloride molecules traveling at slightly higher height than U-235 tetrachloride molecules
  - wasn’t true separation of uranium tetrachloride molecules as illustrated in this graphic
  - only small amount of heavier molecule could be removed from gas stream in each calutron

Slide 20 – plutonium project

- isotope created in plutonium discovery was Pu-240
- plutonium production and processing facilities were going to require lots of electricity; abundant electricity available from Grand Coulee hydroelectric dam on Columbia River

Slide 21 – cyclotron graphic

- graphic side-view shows how cyclotron used to accelerate deuterons at uranium target
  - positively-charged deuterons accelerated around two D-shaped cavities

- upper and lower electromagnets cause deuterons to traverse circular path within D-shaped cavities
- electric field accelerates deuterons at each gap between D-shaped cavities
- as deuteron speed increases, circular path increases in diameter until energetic deuterons exit cavities and directed at uranium target

Slide 22 – cyclotron graphic (cont.)

- graphic top-view shows path of deuterons within cyclotron
- electromagnets above and below D-shaped cavities create magnetic field that causes deuterons to follow circular path within cavities
- electric field in space between cavities accelerates deuterons to increase diameter of circular path

Slide 23 – plutonium production from U-238 graphic

- in plutonium production reactor, U-238 converted to Pu-239 by capturing neutron as shown in graphic
- also evident from graphic, Pu-239 nucleus has 27% probability of capturing neutron to create Pu-240 and 73% probability of undergoing fission
- problem Pu-240 creates for plutonium atomic bomb – undergoes spontaneous fission at small but significant rate, thereby creating free neutrons that cause premature fission of Pu-239 (decreases bomb energy yield)

Slide 24 – Pu isotope buildup with irradiation time graphic

- graphic illustrates buildup of plutonium isotopes as function of U-238 irradiation time in reactor
- since Pu-240 spontaneously fissions, its presence in plutonium used for atomic bomb causes premature fission of Pu-239 atoms, adversely affecting weapon yield
- for plutonium bomb to function properly, plutonium composition must be >93% Pu-239, or <7% Pu-240
- irradiation of U-238 in plutonium production reactor must be limited to 1-2 months to limit buildup of Pu-240; requires reactor that can be fueled online

Slide 25 – Pu-239 fission graphic

- Pu-239 fissions similar to U-235 fission, but with release of slightly more energy and larger average number of neutrons

Slide 26 – Hanford B Reactor photo

- Hanford B plutonium production reactor developed from what Enrico Fermi and his team demonstrated when they obtained self-sustaining fission chain reaction at world’s first small-scale nuclear reactor in Chicago in 1942

Slide 27 – Hanford T Plant photo

- T Plant was chemical processing plant where highly radioactive reactor fuel put through series of chemical processes that eventually extracted small amount of plutonium
- by August 1945, enough plutonium-239 produced for three plutonium atomic bombs

Slide 30 – gun-type assembly device graphic

- graphic depicts uranium atom bomb (Little Boy) dropped on Hiroshima, Japan on August 6, 1945
- when hollow U-235 “bullet” enclosed cylinder target of U-235 to make super-critical mass, neutron generator in nose of bomb activated to produce neutrons that initiated fission chain reaction

Slide 31 – implosion-type device graphic

- graphic depicts plutonium atom bomb (Fat Man) dropped on Nagasaki, Japan on August 9, 1945
- explosive lenses (slow explosive) converted planar shock waves generated by fast explosives into spherical shockwaves to obtain completely symmetrical compression of plutonium core
- compression of plutonium core activated internal neutron initiator that produced neutrons to begin fission chain reaction
- since Fatman bomb had 32 separate detonators, had to be tested because scientists not confident they could achieve simultaneous initiation of all 32 detonators
  - asymmetrical compression of plutonium core doesn’t produce supercritical mass configuration necessary for atomic bomb

Slide 35 – Trinity test photos

- test device, codenamed Gadget, suspended from top of 100-foot-tall tower for test

Slide 36 – Trinity test photo (cont.)

- test device detonated around 5:30 in morning on July 16, 1945 in between electrical storms

Slide 52 – relative atomic bomb fatality map for Albuquerque

- graphic simulates airburst of Fatman bomb with yield of 21 kilotons of TNT equivalent over downtown Albuquerque
- graphic illustrates different spheres of effects
  - ground zero is 4th Street and Marquette Ave.
  - fireball radius is 0.14 miles from ground zero (area of 0.06 square miles)
  - lethal radiation radius is 0.7 miles from ground zero (area of 1.5 square miles)
  - severe shockwave damage radius is 1.2 miles (area of 4.5 square miles)
  - thermal radiation zone (3rd degree burns) radius is 1.3 miles from ground zero (from University Blvd. on east to

Albuquerque Country Club on west, and from I-40 on north to Cesar Chavez Ave. on south – 5.3 square miles)

- note that limit of fatal prompt radiation sphere around point of detonation is well within limits of fatal sphere for blunt force trauma (severe shockwave); in other words, those who survive shockwave do not receive lethal radiation doses